Population Consequences of Acoustic Disturbance of Marine Mammals

Erica Fleishman
University of California, Santa Barbara and Davis
John Muir Institute of the Environment
The Barn
One Shields Ave.
University of California
Davis, CA 95616
phone: (530) 754-9167 fax: (530) 754-9141 email: efleishman@ucdavis.edu

Award Number: N00014-09-1-0896

LONG-TERM GOALS

The long-term goal of this project was to improve understanding of the effects of sound and other anthropogenic and natural disturbances on probabilities of population-level or species-level persistence of marine mammals. Disturbances can lead to alterations in physiological or behavioral states of animals, which in turn may lead to changes in demographic rates and viability. Population-level effects of disturbance also may cascade among species. However, it has proven difficult to identify and model the mechanisms by which individual-level responses might propagate to the population level. A clear and ideally quantitative understanding of such mechanisms is necessary to assess trade-offs between potential responses of species to disturbance and diverse human activities.

OBJECTIVES

1. Explore how the U.S. National Research Council (NRC) committee's 2005 conceptual model of population-level effects of changes in behavior of marine mammals might be translated into quantitative models.
2. Consider how the NRC committee's conceptual model might be parameterized with existing or emerging data on the responses of large vertebrates to disturbance.
3. Define conceptual approaches for investigating transfer functions (e.g., time-energy budgets, trait-mediated responses).
4. Expand work by the NRC to include sensitivity analyses of different transfer functions.
5. Outline exploratory models that might be used to model transfer functions, synthesize existing knowledge, examine potential mechanisms, or inform research and management.

APPROACH

Work was conducted by a multidisciplinary research team of approximately 15 core participants with oversight from a steering committee [Dan Costa (University of California, Santa Cruz), Erica Fleishman, John Harwood (University of St. Andrews), Scott Kraus (New England Aquarium), and

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**
4. TITLE AND SUBTITLE **Population Consequences of Acoustic Disturbance of Marine Mammals**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California, Santa Barbara and Davis,John Muir Institute of the Environment, The Barn,One Shields Ave,Davis,CA,95616**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Mike Weise (Office of Naval Research)]. Peter Tyack (University of St. Andrews, formerly Woods Hole Oceanographic Institution) served on the steering committee through June 2012. Kraus joined the steering committee in July 2012. Additional participants contribute to some aspects of the project. The team met in person approximately every six months to iteratively develop and interpret models and refine deliverables. Participants conducted the majority of analyses and writing at their home institutions between meetings.

Throughout the project, core participants were Jim Clark (Duke University), Dan Costa, John Harwood, Mark Hindell (University of Tasmania), Scott Kraus, David Lusseau (University of Aberdeen), Clive McMahon (Charles Darwin University), Dave Moretti (Naval Undersea Warfare Center), Leslie New (United States Geological Survey, formerly University of St. Andrews and Marine Mammal Commission), Rob Schick (Duke University), Lisa Schwarz (University of California, Santa Cruz), Sam Simmons (Marine Mammal Commission), Len Thomas (University of St. Andrews), and Peter Tyack.

WORK COMPLETED

Participants convened in person five times: 28 September–1 October 2009 (Santa Barbara, California), 4–6 March 2010 (Santa Barbara, California), 7–9 September 2010 (Woods Hole, Massachusetts), 10–12 April 2011 (Atlantic Undersea Test and Evaluation Center [AUTEC], Andros Island, Bahamas), and 22–24 October 2011 (Washington, D.C.). A total of 31 individuals participated in these meetings: 17 based at universities (10 in the United States); five based at aquaria, zoological societies, or museums (four in the United States); two based at other research organizations (one in the United States); five based at resource agencies in the United States; and two with the Navy. Seven participants were female and five were early in their careers.

During the first meeting, the group developed a model for analyzing energy change during foraging trips by northern and southern elephant seals (*Mirounga angustirostris* and *M. leonina*, respectively) and the effects of this energy change on pup survival. During the second meeting, the group began to develop a model for coastal populations of bottlenose dolphins (*Tursiops* spp.). The third meeting focused on how disturbance might affect northern right whales (*Eubalaena glacialis*). During the fourth meeting, the group developed a model for Blainville's beaked whales (*Mesoplodon densirostris*) on the AUTEC range. During the fifth meeting, the group reviewed progress to date and discussed objectives and logistics for the next phase of the work.

On 21 October 2011, a subset of the project team participated in a symposium in Washington, D.C. that was cosponsored by ONR and the Marine Mammal Commission. Nine presentations introduced the audience to project objectives, methods, preliminary results, and potential applications to decision-making and management.

Fleishman and Thomas delivered presentations based all or in part on the project at the Biennial Conference on the Biology of Marine Mammals in Tampa, Florida, in December 2011. Harwood presented project research at a workshop on effects of marine anthropogenic sound in Bristol, United Kingdom, in February 2012 and a workshop on managing risk to marine mammals from marine renewables devices in Edinburgh, United Kingdom, in March 2012.

RESULTS

We used long-term telemetry data on female southern elephant seals at Macquarie Island, Australia to model the effect of behavior on the seals' health (i.e., all internal factors that affect homeostasis). Through simulation, we examined whether the exclusion of reproductive females from foraging habitat affects their health, individual fitness, survival of their offspring, and population growth rate. A long period of altered behavior (> 50% of an average foraging trip at sea) in one year resulted in a small (0.4%) decline in population size the following year. However, a persistent disruption (e.g., 30 years), which might be caused by changes in climate to which the species cannot rapidly adapt, could result in a 0.3% decline in individual fitness and a 10% decline in population size. Our methods for estimating the long-term population-level effects of short-term changes in individual behavior are transferable to other species. The models can include physiological effects and other environmental changes, whether anthropogenic or natural, that affect behavioral and physiology.

We used 17 years of data on southern elephant seals marked with both permanent brands and two cattle tags in their hind flippers to compare tag loss and survival-rate estimates with and without the assumption of independent tag loss with respect to age, sex, and wean mass. We found that the assumption of independent tag loss was not supported: it was more likely for an animal to lose both tags than one tag. The assumption of independent tag loss leads to underestimation of survival rates and, in turn, underestimation of population growth rate. Additionally, tag loss rates varied as a function of sex and age: older males were most likely to lose tags. Tag loss also was a quadratic function of wean mass through age two, with smaller and larger animals more likely to lose both tags. Such differences may reflect differences in behavior, flipper growth, and immune response. Accounting for non-independent mark loss in survival-rate studies may warrant at least two forms of marking on at least a subset of animals. However, neither form of marking need be permanent if mark loss is independent between the forms.

We found that physiological condition of northern elephant seals and southern elephant seals had a substantial association with lipid gain. Northern elephant seals generally lost lipids as they moved away from the colony following the annual molt. They gained lipid rapidly during their foraging period, then lost lipid during their return to the colony. By contrast, southern elephant seals lost relatively little lipid early in the post-molt trip, but gained less absolute lipid than northern elephant seals. In both species, lipid gain was a function of percentage lipid at departure and lipid to lean mass ratio. Southern elephant seals made fewer drift dives than northern elephant seals and gained lipids at a lower rate.

We modeled social, spatial, behavioral, and motivational interactions of coastal bottlenose dolphins (*Tursiops truncatus*) in the Moray Firth, Scotland, to assess the biological effects of vessel traffic-induced behavioral changes. When we simulated an increase in vessel traffic from 70 to 470 vessels a year, the dolphins' behavioral time budget, spatial distribution, motivations, and social structure did not change. Our results suggested that the dolphins were able to compensate for their immediate behavioral response to commercial vessel traffic. Accordingly, health, vital rates, and population dynamics were not affected.

Results from our models of relations between feeding energetics and survival and reproduction suggested that beaked whales (family Ziphiidae) require energy-dense prey to reproduce, and food limitation extends the interval between reproduction of offspring. Our results indicated that some beaked whale species require relatively high-quality habitat to survive and reproduce. Species with

relatively short lactation periods generally had lower survival and reproduction than species with longer lactation periods. When habitat quality was relatively low, the duration of lactation was extended. Survival of fetuses and calves was more strongly related to habitat quality than survival of adult females. Our results suggest that adult female beaked whales survive, but do not reproduce, during periods or in locations with relatively lower habitat quality.

APPLICATIONS

Multiple public and private sectors wish to understand whether observed changes in animals' behavior or physiology affect probabilities of persistence. Subsistence hunters also wish to understand whether short-term changes in behavior may affect long-term spatial distributions of animals. The concept that behavioral responses to disturbance are not necessarily surrogate measures of population-level responses is widely understood. However, without tractable methods for quantifying population-level effects, most sectors will be restricted to estimating exposure of individual animals to disturbances, changes in habitat quantity or quality, and behavioral responses of individual animals. Thus, improved understanding of transfer functions might help to guide research and management, and to project how marine mammals will respond to alternative scenarios of human activities, from those that produce sound to climate change to changes in human density and distributions. Deliverables and inferences from the team's work, and direct communication with potential end-users, may inform national and international legislation and scientific guidance on managing marine mammals. Examples include the Endangered Species Act and the Marine Mammal Protection Act in the United States, the IUCN Red List categories and criteria, and the Species and Habitats Directive in the European Union.

RELATED PROJECTS

Fleishman is leading a project on cumulative effects of underwater anthropogenic sound on marine mammals for BP Exploration. There are no standards for assessment of cumulative effects of underwater sound. Quantitative assessments typically consider a single source of sound whereas qualitative assessments may include multiple sources but rarely identify response variables. The project has developed both quantitative and qualitative methods for assessing the aggregated sounds of multiple sources received by a given species during a defined time period in a defined location. The quantitative method models the sound field from multiple sources and simulates movement of a population through it. The qualitative method uses expert knowledge to assess responses of individuals and populations to sound sources and identify potential mechanisms. The ONR-sponsored project is highly complementary because it quantifies mechanisms by which responses to sound or other disturbances may affect survival, reproduction, and population viability.

In April, 2012, ONR funded a second phase of the working group's collaboration. This work is based on four major activities. First, participants are completing models initiated during the first phase of the project or expanding on previous work to increase its generality. Second, the group is prioritizing data collection to estimate population-level effects of different classes of disturbance on marine mammals with different life-history attributes. Third, the working group is examining inferences about effects of disturbance on individuals and populations that can be drawn on the basis of limited empirical information. Fourth, the group is comparing inferences about population-level effects of disturbance that are based on extensive empirical data to those based on expert elicitation, and applying expert elicitation to parameterize models in the absence of empirical data.

PUBLICATIONS

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